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Engineering Design File

Seismic Evaluation of Landfill and Evaporation Pond

INEEL

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5. Summary:

This report presents the evaluation of the INEEL CERCLA Disposal Facility (ICDF) landfill and evaporation pond under seismic loading. Seismic evaluation of structures and equipment associated with the ICDF and evaporation ponds is also presented. These evaluations are based on the guidance provided in the Department of Energy Idaho Operations Office (DOE-ID) Architectural Engineering Standards (DOE-ID 2000a; DOE-ID 2000b).

Evaluations included a review of ARAR and DOE seismic design criteria to establish design basis earthquake (DBE) parameters for the ICDF and evaporation ponds and associated structures. This includes the site-specific design response spectra for estimation of peak-ground acceleration levels, corresponding to the appropriate hazard classification, at the site. These estimated peak-ground acceleration levels are then compared to the required peak-ground acceleration levels to achieve the minimum acceptable factor of safety (FS) for the seismic loading condition.

Results of these analyses concluded that the ICDF landfill and evaporation ponds are stable under seismic loading conditions.

6. Review (R) and Approval (A) and Acceptance (Ac) Signatures:
(See instructions for definitions of terms and significance of signatures.)

	R/A	Typed Name/Organization	Signature	Date
Performer		Mike Reimbold/ CH2M HILL	Mike Reimbold	05/14/02
Checker	R	(Same as Independent Peer Reviewer)		05/14/02
Independent Peer Reviewer	A	Marty Doornbos/ BBWI	Marty Doornbos	05/14/02
Approver	A	Thomas Borschel/ BBWI	Thomas F. Borschel	05/14/02
Requestor	Ac	Don Vernon/ BBWI	D. Vernon	05/14/02

7. Distribution: (Name and Mail Stop)	M. Doornbos, MS 3930; D. Vernon, MS 3930; T. Borschel, MS 3930
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ABSTRACT

This report presents the evaluation of the INEEL CERCLA Disposal Facility landfill and evaporation pond under seismic loading. Seismic evaluations of structures and equipment associated with the INEEL CERCLA Disposal Facility and evaporation ponds are also presented. These evaluations are based on the guidance provided in the Department of Energy Idaho Operations Office Architectural Engineering Standards.

Evaluations included a review of Department of Energy seismic design criteria to establish design basis earthquake parameters for the INEEL CERCLA Disposal Facility and evaporation ponds and associated structures. This includes the site-specific design response spectra for estimation of peak-ground acceleration levels, corresponding to the appropriate hazard classification, at the site. These estimated peak-ground acceleration levels are then compared to the required peak-ground acceleration levels to achieve the minimum acceptable factor of safety for the seismic loading condition.

CONTENTS

ACRONYMS

ARAR	applicable or relevant and appropriate requirement
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
DBE	design basis earthquake
DOE	U.S. Department of Energy
DOE-ID	Department of Energy Idaho Operations Office
EDF	engineering design file
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FS	factor of safety
g	acceleration due to gravity
ICDF	INEEL CERCLA Disposal Facility
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
k	seismic coefficient
NRC	Nuclear Regulatory Commission
PC	Performance Category
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
TFR	Technical and Functional Requirements
UBC	Uniform Building Code

Seismic Evaluation of Landfill and Evaporation Pond

1. INTRODUCTION

This report presents the evaluation of the INEEL CERCLA Disposal Facility (ICDF) landfill and evaporation pond under seismic loading. Seismic evaluation of structures and equipment associated with the ICDF and evaporation ponds is also presented. These evaluations are based on the guidance provided in the Department of Energy Idaho Operations Office (DOE-ID) Architectural Engineering Standards (DOE-ID 2000a; DOE-ID 2000b).

Evaluations included a review of Department of Energy (DOE) seismic design criteria to establish design basis earthquake (DBE) parameters for the ICDF and evaporation ponds and associated structures. This includes the site-specific design response spectra for estimation of peak-ground acceleration levels, corresponding to the appropriate hazard classification, at the site. These estimated peak-ground acceleration levels are then compared to the required peak-ground acceleration levels to achieve the minimum acceptable factor of safety (FS) for the seismic loading condition.

2. SEISMIC DESIGN CRITERIA

The ICDF Complex is a DOE Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) facility, and as such must meet the design requirements of 40 Code of Federal Regulations (CFR) 264.18 (Operable Unit [(OU)] 3-13 Record of Decision [(ROD)], DOE-ID 1999) and DOE standards 1020-94 and 1022-94.

2.1 ARAR Seismic Design Criteria

40 CFR 268.14 requires that portions of new facilities where treatment, storage, or disposal of hazardous waste will be conducted, must not be located within 61 m (200 ft) of a fault that has had displacement during Holocene time. The OU 3-13 ROD in selecting the ICDF site concluded that there were no active seismic faults that met this criteria within 200 ft of the ICDF site. These findings were further confirmed during geophysical studies performed for the ICDF geotechnical investigation and report (DOE-ID 2000c).

The ICDF Complex is located in Butte County, which is not an Appendix VI Political Jurisdiction in which compliance with 40 CFR 264.18(a) must be demonstrated.

2.2 DOE Seismic Design Criteria

Through the Natural Phenomena Hazards Project, the DOE has, in recent years, focused on addressing the potential hazards that might affect their facilities due to earthquakes, wind, tornadoes, and floods. As a result of this effort, the DOE requires that all structures, systems, and components at DOE facilities be designed and constructed to withstand the effects of natural hazards including earthquakes.

DOE Standards have been developed to aid in the definition of seismic design basis vibratory ground motion for DOE facilities (DOE Standard 1020-94; DOE Standard 1022-94). These documents contain appropriate methods and acceptance criteria for evaluating seismic hazards to ensure a consistent approach for all DOE sites.

In an effort to update its seismic design standard, the DOE initiated a site-specific seismic study in the early 1990s. Concurrent with this performance study, hazard exceedance probability curves were developed to define the seismic design parameters for the Idaho National Engineering and Environmental Laboratory (INEEL) site (Woodward-Clyde et al. 1996). These hazard curves were specified according to four Performance Categories (PC), namely:

1. General Use (500-year earthquake)
2. Important or Low Hazard (1,000-year earthquake)
3. Moderate Hazard (2,500-year earthquake)
4. High Hazard (10,000-year earthquake).

In an attempt to locate design guidance for the ICDF landfill and evaporation pond, a review was conducted of National Regulatory Commission (NRC) and Environmental Protection Agency (EPA) Resource Conservation and Recovery Act (RCRA) Subtitle C requirements. NRC requirements are not applicable to the waste categories that will be managed within the ICDF Complex and Subtitle C does not provide specific guidance regarding the DBE for use in seismic analysis. Thus, Subtitle D requirements were used as a basis for this evaluation. Seismic design of structures and facilities associated with the landfill and evaporation pond are dictated by the Technical and Functional Requirements (TFR) established for the ICDF (TFR-71, 2002). A detailed discussion of the seismic design parameters for ICDF structures and equipment is provided in Section 6.

For design of solid waste landfill facilities, the current requirements for seismic design are governed by the RCRA Subtitle D regulations. These regulations require that a DBE with 2,500-year return period be used. This DBE corresponds to an acceleration level with a 90% probability of non-exceedance over a 250-year period. Based on DOE Standard 1021-93 as discussed above, a 2,500-year return period is equivalent to a PC-3 hazard. Because of the lack of specific guidance in RCRA Subtitle C and because its requirements are likely more stringent than RCRA Subtitle D, the seismic evaluation for the ICDF landfill and evaporation pond will be conducted using the following approach:

- Determine the required peak-ground acceleration (a_{req}) to achieve the minimum FS for the seismic loading case.

- Compare this required peak-ground acceleration level to the equivalent peak-ground acceleration (a_{PC4}) corresponding to a PC-4 hazard (return period of 10,000 years).

- If a_{req} is greater than a_{PC4}, then the facility is seismically stable for a PC-4 hazard earthquake and evaluation of the precise PC classification will be unnecessary.

- If a_{req} is less than a_{PC4}, then an evaluation of the precise PC classification will be conducted to specifically determine the peak-ground acceleration level and the associated FS.

3. SITE-SPECIFIC SEISMIC DESIGN PARAMETERS

The site-specific probabilistic hazard parameters for the INEEL site as contained in Appendix S of the DOE-ID Architectural Engineering Standards (DOE-ID 2000b) will be used to design the ICDF landfill and evaporation pond side slopes and lining systems. These seismic design parameters were developed by Payne et al. (2000) for INEEL and typically consist of response spectra (acceleration, velocity, and displacement) for various damping. Seismic parameters that are specific to the Idaho Nuclear Technology and Engineering Center (INTEC) site, located just northeast of the ICDF Complex, are considered appropriate. Typical DBE spectra for horizontal acceleration on rock and soil for the INTEC site are shown in Tables A-1 through A-4 of Appendix A. These spectra correspond to earthquakes with return periods of 2,500 and 10,000 years. As discussed in Section 2, the 2,500-year return period earthquake is similar to the design earthquake level required by RCRA Subtitle D for seismic design of landfill facilities (or for a PC-3 hazard) while the 10,000-year return period earthquake is similar to that required for a PC-4 hazard.

4. METHODOLOGY FOR SEISMIC STABILITY EVALUATION

The first step in assessing the seismic stability of ICDF landfill and evaporation pond side slopes and lining systems is to select appropriate earthquake design criteria. As described in Section 2, it will be assumed that the ICDF landfill and evaporation pond will be designed for a DBE that is equivalent to an earthquake event with a return period of 10,000 years. This criterion applies to the final landfill configuration. Accordingly, much lower design periods can be associated with the temporary construction cases compared to the 10,000-year design event associated with the final landfill configuration.

The tables in Appendix A present the spectral accelerations for the 2,500-year (Tables A-1 and A-2) and 10,000-year (Tables A-3 and A-4) return period earthquake at various damping values and frequencies. In these tables the peak-ground acceleration is equal to the spectral acceleration at high frequencies (e.g., frequencies > 50 Hz). The peak horizontal ground acceleration can be obtained from the DBE response spectra information in Tables A-1 through A-4 of Appendix A by using the acceleration value at high frequencies (e.g., 50 to 100 Hz). At high frequencies, the single degree of freedom system used to derive the response spectra values responds at a level equivalent to the input acceleration level. This means that a convenient method of determining the peak horizontal ground motion is to use a value at very high (i.e., 50 to 100 Hz) frequencies or very low periods, often referred to as the zero period acceleration, where period is the reciprocal of the frequency.

The peak-ground acceleration is essentially independent of viscous damping in the free-field at viscous damping ratios ranging from 2% to 10% (see Tables A-1 through A-4). Five percent damping is assumed as this assumption provides a degree of conservatism to the design. It is conservative because for soil embankments (such as the waste mass at the ICDF) damping can be higher than 5%. Higher damping results in more energy loss within any vibrating system. The consequence of this energy loss is a lower level of acceleration at periods removed from the zero period acceleration. The zero period of acceleration remains the same for all damping values.

As indicated in Table A-3, this peak-ground acceleration is applicable to rock sites or sites located within a few feet above bedrock. Table A-4 of Appendix A shows the spectral acceleration applicable to sites with 30 to 50 ft of soil. Values of peak-ground acceleration obtained from Table A-3 are applicable for seismic stability evaluations of the waste mass for Cell 1 and Cell 2 since the base of the waste for both cells is at or very close to bedrock. On the other hand, values of peak-ground acceleration estimated from Table A-4 are applicable to seismic stability analysis of the final cover since the base of the cover is located above a 30- to 50-ft thickness of soil.

Thus, for the ICDF landfill and evaporation pond lining system and waste mass, the design peak-ground acceleration corresponding to 5% damping and the highest frequency is 0.187g. For the ICDF landfill and evaporation pond final cover, the design peak-ground acceleration corresponding to 5% damping and the highest frequency is 0.363g.

A detailed seismic stability evaluation of the ICDF landfill and evaporation pond was conducted using the program PCSTABL5 (FHWA 1988) and employing pseudo-static methods of analysis. This procedure is similar to a static slope stability analysis except that the effect of earthquake loading is added as a horizontal inertial force acting at the centroid of the critical sliding surface. The intensity of seismic loading in the PCSTABL5 analysis will be specified in terms of a seismic coefficient, k, which was defined as one-half of the peak bedrock acceleration divided by the acceleration due to gravity, g. Use of the peak-ground acceleration for k in conjunction with a pseudo-static FS of 1.0 has been shown to give excessively conservative assessments of slope performance in earthquakes (EPA 1994). This definition of k allows the transient pulsating nature of the earthquake to be represented as an equivalent horizontal load that is applied continuously and in one direction only. Experience has been that if the FS under the simulated earthquake loading is equal to or greater than 1.0, displacement of the slope will be less than 3 ft (Hynes and Franklin 1984; EPA 1994). The resulting FS of the landfill slope from the pseudo-static analysis is compared to the minimum acceptable value. A typical requirement is to use a minimum FS of 1.1 for short-term seismic loading conditions to limit movement of the landfill slope. As discussed in "Slope Stability Assessments" (EDF-ER-268), for long-term seismic evaluation of sensitive sites, a FS of 1.3 is typically required. Results of seismic stability analyses are presented in "Slope Stability Assessments" (EDF-ER-268).

If the actual FS calculated from the pseudo-static approach is less than acceptable, seismic permanent deformation analysis (using the Newmark approach [Hynes and Franklin 1984; Makdisi and Seed 1978]) would be performed to supplement the results of pseudo-static analysis. In the Newmark approach, the performance of the landfill is judged based on the estimated amount of deformation that the landfill will undergo during a seismic event. The estimated deformation would then be compared to the deformation that is acceptable in current practice.

5. RESULTS OF SEISMIC EVALUATION FOR THE ICDF AND EVAPORATION POND

Seismic stability evaluations have been conducted for the ICDF landfill and evaporation pond as part of the slope stability assessment task conducted for this project. This evaluation has been briefly discussed in the report entitled "Slope Stability Assessments" (EDF-ER-268). In the seismic stability evaluation, analyses were limited to determination of seismic acceleration levels to achieve the required minimum FS for a specified loading condition. Specifically, the seismic analyses were included in both the veneer and global stability analyses of Cell 1 landfill and final cover configuration and the global stability analysis of the evaporation ponds presented in "Slope Stability Assessments" (EDF-ER-268). Because of similarity in the geometry of Cell 1 and Cell 2, the analyses results for Cell 1 are also applicable to Cell 2.

Results of the seismic stability evaluation indicate the following:

- For the veneer stability analysis, the lowest acceleration level corresponding to a minimum acceptable FS of 1.1 (for temporary loading) for the Cell 1 landfill is approximately 0.2g. For the final cover, the lowest acceleration level corresponding to a minimum acceptable FS of 1.3 (for long-term loading conditions) is approximately 0.6g.

- For the global stability, the lowest acceleration level required to decrease the FS to a minimum acceptable level (that is, 1.3 for long-term condition) for Cell 1 is approximately 0.22g for the waste and 0.90g for the final cover. The corresponding lowest acceleration level for the evaporation ponds is about 0.74g.

The above acceleration levels correspond to the acceleration a_{req} discussed in Section 2 and represent the levels of seismic ground motion that will cause minimum values of FS. For values of peak-ground acceleration that are lower than that of a_{req}, the corresponding FS should be higher than the minimum specified for that loading case.

As discussed in Section 4, the peak-ground acceleration corresponding to a return period of 10,000 years and 5% damping is 0.187g for the ICDF landfill lining system and waste mass (see Table A-3) and 0.363g (see Table A-4) for the final cover. These acceleration values are equivalent to that of a_{PC4} described in Section 2. Since the peak-ground acceleration level for a 10,000-year return period (a_{PC4}) is less than the values of a_{req}, it can be concluded that the proposed ICDF landfill and evaporation pond design satisfies the minimum FS requirements even for a more stringent PC-4 hazard classification and, therefore, a more precise PC classification is not warranted. Additionally, it can be concluded that the ICDF landfill and evaporation pond lining systems, waste mass, and final cover are stable under seismic loading conditions. Since acceptable FS were achieved for all seismic loading conditions, deformation analyses as described in Section 4 are not required.

6. STRUCTURES AND EQUIPMENT

Seismic design parameters used to evaluate the stability of the ICDF landfill and ICDF evaporation pond side slopes and lining systems were determined based on RCRA requirements as discussed in Section 2. These evaluations concluded that applying a DBE associated with a stringent PC-4 hazard classification satisfied the minimum FS requirements for the proposed ICDF and evaporation pond. However, a more precise PC classification for structures and equipment associated with the ICDF was desired, as to avoid an unnecessarily conservative design for these facilities. Structures and equipment for the ICDF include the crest pad buildings, truck load platform, and associated piping and equipment.

A review of the TFR for the ICDF (TFR-71, 2002) indicates that the PC-1 hazard classification has been assigned to the ICDF. This is based on the DOE-ID Standards for Structures, Systems, and Components (DOE STD-1021) which is less stringent than the RCRA Standard that applies to the landfill and evaporation pond side slopes and lining system.

Section 0111 of the DOE-ID Architectural Standards (DOE-ID 2000a) provides guidance for seismic design of structures at INEEL. The standard dictates that for structures with PC-1 and PC-2 hazard classification, the Uniform Building Code (UBC) should be used for seismic design. According to the UBC, the ICDF site is in seismic zone 2b. Thus, the seismic design parameters for UBC seismic zone 2b were used for design of the crest pad buildings, truck load platform, and associated piping and equipment. Detailed calculations for seismic design of structures and equipment is provided in the "Landfill Leachate Collection System Design Analysis" (EDF-ER-280) along with other structural calculations for these facilities.

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Appendix A

Site-Specific Seismic Spectral Acceleration

Table A-1. PC 3 (2,500 years) horizontal rock DBE response spectra at 5, 2, 3, 7 and 10% damping for INTEC, TRA, RWMC, and PBF.

		Horizontal Spectral		
Damping	Frequency (Hz)	Acceleration (g)	Velocity (in./sec)	Displacement (in.)
5%	100	0.1230	0.0756	0.0001
	50	0.1230	0.1513	0.0005
	33	0.1540	0.2870	0.0014
	8	0.2930	2.2523	0.0448
	2.1866	0.2930	8.2407	0.5998
	0.3279	0.0439	8.2407	4.0000
	0.1	0.0041	2.5133	4.0000
2%	100	0.1230	0.0756	0.0001
	50	0.1230	0.1513	0.0005
	36.3969	0.1873	0.2870	0.0014
	9.8038	0.4400	2.7602	0.0448
	2.3868	0.4400	11.3375	0.7560
	0.3983	0.0734	11.3375	4.5300
	0.1	0.0046	2.8463	4.5300
3%	100	0.1230	0.0756	0.0001
	50	0.1230	0.1513	0.0005
	34.7947	0.1712	0.2870	0.0014
	8.9764	0.3689	2.5272	0.0448
	2.2734	0.3689	9.9786	0.6986
	0.3734	0.0606	9.9786	4.2532
	0.1	0.0043	2.6724	4.2532
7%	100	0.1230	0.0756	0.0001
	50	0.1230	0.1513	0.0005
	32.1148	0.1458	0.2870	0.0014
	7.4931	0.2570	2.1096	0.0448
	2.1963	0.2570	7.1974	0.5216
	0.2976	0.0348	7.1974	3.8496
	0.1	0.0039	2.4188	3.8496
10%	100	0.1230	0.0756	0.0001
	50	0.1230	0.1513	0.0005
	31.3957	0.1394	0.2870	0.0014
	7.0659	0.2286	1.9893	0.0448
	2.2623	0.2286	6.2135	0.4371
	0.2622	0.0265	6.2135	3.7716
	0.1	0.0039	2.3698	3.7716

Table A-2 Horizontal and vertical PC 3 (2,500 years) soil DBE 5% damped response spectra for 30 to 50 ft soil thickness at INTEC.

		Spectral		
Component	**Frequency (Hz)**	**Acceleration (g)**	**Velocity (in./sec)**	**Displacement (in.)**
Horizontal	100	0.2538	0.1561	0.0002
	50	0.2538	0.3122	0.0010
	12	0.7646	3.9184	0.0520
	3.829	0.7646	12.280	0.5104
	0.181	0.0362	12.280	10.766
	0.100	0.0110	6.7647	10.766
Vertical	100	0.1954	0.1202	0.0002
	50	0.1954	0.2404	0.0008
	15	0.6484	2.6584	0.0282
	4.764	0.6484	8.3710	0.2797
	0.189	0.0257	8.3710	7.0505
	0.1	0.0072	4.4300	7.0506

Table A-3 PC 4 (10,000 years) horizontal rock DBE response spectra at 5, 2, 3, 7 and 10% damping for INTEC, TRA, RWMC, and PBF.

		Horizontal Spectral		
Damping	Frequency (Hz)	Acceleration (g)	Velocity (in./sec)	Displacement (in.)
5%	100	0.1870	0.1150	0.0002
	50	0.1870	0.2300	0.0007
	33	0.2420	0.4510	0.0022
	8	0.4570	3.5130	0.0699
	2.0586	0.4570	13.6524	1.0555
	0.3621	0.0804	13.6524	6.0000
	0.1	0.0061	3.7699	6.0000
2%	100	0.1870	0.1150	0.0002
	50	0.1870	0.2300	0.0007
	36.3843	0.2942	0.4510	0.0022
	9.8097	0.6871	4.3077	0.0699
	2.2486	0.6871	18.7926	1.3301
	0.4421	0.1351	18.7926	6.7656
	0.1	0.0069	4.2510	6.7656
3%	100	0.1870	0.1150	0.0002
	50	0.1870	0.2300	0.0007
	34.7944	0.2690	0.4510	0.0022
	8.9832	0.5762	3.9448	0.0699
	2.1376	0.5762	16.5782	1.2344
	0.4158	0.1121	16.5782	6.3462
	0.1	0.0065	3.9874	6.3462
7%	100	0.1870	0.1150	0.0002
	50	0.1870	0.2300	0.0007
	32.1192	0.2293	0.4510	0.0022
	7.4919	0.4008	3.2899	0.0699
	2.0656	0.4008	11.9322	0.9194
	0.3279	0.0636	11.9322	5.7912
	0.1	0.0059	3.6387	5.7912
10%	100	0.1870	0.1150	0.0002
	50	0.1870	0.2300	0.0007
	31.3857	0.2189	0.4510	0.0022
	7.0523	0.3551	3.0969	0.0699
	2.1157	0.3551	10.3226	0.7765
	0.2876	0.0483	10.3226	5.7132
	0.1	0.0058	3.5897	5.7132

Table A-4 Horizontal and vertical PC 4 (10,000 years) soil DBE 5% damped response spectra for 30 to 50 ft soil thickness at INTEC.

		Spectral		
Component	**Frequency (Hz)**	**Acceleration (g)**	**Velocity (in./sec)**	**Displacement (in.)**
Horizontal	100	0.3630	0.2275	0.0004
	50	0.3630	0.4551	0.0014
	10	1.1130	6.8447	0.1089
	3.523	1.1130	19.4290	0.8777
	0.257	0.0814	19.4290	12.0000
	0.1	0.0123	7.5398	12.0000
Vertical	100	0.2849	0.1752	0.0003
	50	0.2849	0.3504	0.0011
	15	0.9323	3.8222	0.0406
	4.425	0.9323	12.9560	0.4660
	0.258	0.0543	12.9560	8.0000
	0.1	0.0082	5.0266	8.0000